HOW SERIOUS ARE GROUNDWATER OVER-EXPLOITATION PROBLEMS IN INDIA? A FRESH INVESTIGATION INTO AN OLD ISSUE

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Abstract

In this paper, first we deal with the definition of aquifer over exploitation. Then a review of the various definitions and criteria for assessing over exploitation is provided. Subsequently, the existing methodologies in India for assessment of groundwater resources are reviewed to examine: the robustness of the criteria used; and the scientific accuracy of the methodologies and procedures suggested. Finally, the current estimates of groundwater over development for India are reviewed from the perspective of detailed water balance, geology, hydrodynamics, and negative social, economic, ecological and ethical consequences.

The paper argues that there are several conceptual issues involved in the assessment of aquifer over exploitation. Over-exploitation is linked to various "undesirable consequences" of groundwater use that are physical, social, economic, ecological, environmental, and ethical in nature. Further, there are differences in the way undesirable consequences are perceived by different stakeholders. The principle of inter-generational equity used in the concept of sustainability, is built in the standard definitions of aquifer over exploitation. But, defining and assessing over exploitation is both difficult and complex, and not amenable to simple formulations.

The criteria used for assessing groundwater development by groundwater estimation committee (GEC) 1984 are only physical, involving variables such as gross groundwater recharge and net abstraction. The criterion adopted by GEC-97 is more rigorous. It involves net groundwater recharge and gross draft. It takes into account some of the complex variables determining net recharge, such as base flow and lateral flows. But, both fail to integrate complex hydrological, geological, hydro-dynamic, social, economic and ethical factors that capture the physical, social, and economic impacts of groundwater overuse. This apart, there are issues of reliability in estimation of net groundwater recharge and draft, due to lack of robustness in the methodologies, owing to the absence of reliable data required for estimation. The official statistics therefore provide a not-so-bad scenario of groundwater in the country. The paper demonstrates through selected illustrative cases how integrating data on complex hydrology, geology, hydro-dynamics, and socio-economic, ecological and ethical aspects of groundwater use, with the official statistics could change India's groundwater scenario altogether. Some of them are: break up of groundwater balance into natural recharge, recharge from imported water, and consumptive water use; specific yield of aquifer; long term and seasonal trends in groundwater levels; economic cost of groundwater abstraction; incidence of well failures and change in well yields; and drinking water scarcity.

1. INTRODUCTION

In India, groundwater resources play a major role in India's irrigation economy, and are crucial for meeting water supply needs of both rural and urban areas (Kumar, 2007). India's ability to manage its future water needs would depend so much on proper understanding of the availability of groundwater, and the nature and magnitude of groundwater problems. There are ever-increasing evidences of aquifer over exploitation in many localities, which cause negative consequences such as drinking water shortage, enormous increase in cost of water abstraction from wells, frequent well failures, reducing command area of wells, increasing inequity in access to well water for irrigation, and ecological degradation such as reduced groundwater table and soil salinity (Kumar, 2007). While concerns over the future of groundwater use in India are growing (GoI, 2007), official statistics continue to paint a rosier picture of groundwater status in the country (GoI, 2005). At the root of the public concern is the need to arrive at a working definition and comprehensive criteria for assessing

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aquifer over exploitation that integrates various concerns such as shortage of water for basic survival needs, poor economics of groundwater use for irrigation, growing inequity in access to water, eco-system and environmental degradation, and unethical water use practices.

Aquifer over exploitation mainly deals with negative aspects of groundwater development (ITGE, 1991; Custodio, 1992 & 2000; Delgado, 1992; Margat, 1992[2]). Scholars have argued that the concept of groundwater over development or aquifer over exploitation is not simple, merely linked to recharge and extraction balance, but is rather complex linked to various undesirable consequences, which are physical, social, economic, ecological, environmental, and ethical in nature. Again, these undesirable consequences also change with perceptions (Custodio, 2000). Hence, defining and assessing groundwater over development is both difficult and complex and not amenable to simple formulations.

Still, the perceptions of official agencies concerned with groundwater development and management, are characterized by aggregate views based on simple hydrological considerations of recharge and abstraction (Kumar and Singh, 2001). Nevertheless, there have been some recent changes in the official perceptions about groundwater over development, as a result of the recognition of the need to integrate economic and social considerations in assessing degree of exploitation. This is also reflected in the methodology proposed by Ground Water Estimation Committee of 1997 (NABARD, 2006). But, how far such concerns are integrated in actual assessment is however, open to question.

2. PURPOSE OF THE PAPER

The paper first discusses some of the conceptual issues in defining groundwater over exploitation; and presents some of the accepted definitions of aquifer over exploitations. It then critiques some of the methodologies used in India for assessing groundwater resources and stages of groundwater development. Finally, the paper demonstrates through illustrative cases in India how integrating some of the complex considerations such as detailed water balance, geology, hydro-dynamics, and negative socio-economic, ecological and ethical consequences of over exploitation, with the official methodologies can yield an altogether different scenario of groundwater, than what the official statistics provide.

3. ASSESSMENT OF GROUNDWATER OVER-EXPLOITATION

In this section, we shall deal with the conceptual issues involved in defining groundwater over development. The discussion will not touch upon the methodological issues involved in assessing groundwater recharge and extraction, but will identify the complex considerations involved in assessing the degree of groundwater over development or aquifer over exploitation. It will then present some of the most common definitions of groundwater over development that use some of these considerations, so as to provide a comprehensive framework for assessing the same.

3.1 Conceptual Issues in Defining Over-exploitation

Terms such as groundwater over exploitation, over draft, over development, overuse and unsustainable use are commonly used in discussions on hydro-geology and groundwater resources since 1970's (Custodio, 2000). Such phenomena are predominantly applied in arid and semi-arid regions where large volumes of groundwater are abstracted to irrigate extensive areas, under situations where the natural recharge to aquifers is limited due to several reasons such as low rainfalls, unfavourable topographic and geo-hydrological environments. They are applied to aquifer conditions in other regions when exploitation leads to undesirable consequences.

The concept of groundwater over exploitation predominantly deals with negative aspects of groundwater development (ITGE, 1991; Custodio, 1992 & 2000; Delgado, 1992; Margat, 1992). Such consequences may include: [i] large and continuous drops in groundwater levels over long time periods; [ii] large

[2] Such consequence may include: large and continuous drops in groundwater levels over long time periods; large seasonal drops in water levels in wells and the drying up of wells in summer season; and increase in salinity of seawater; land subsidence; enormous increase in cost of groundwater extraction; and reduction of groundwater dependent vegetation and springs and seepage.

seasonal drops in water levels in wells and the drying up of wells in summer season; and [iii] increase in salinity of groundwater; [iv] land subsidence; [v] enormous increase in cost of groundwater extraction; and [vi] reduction of groundwater dependent vegetation and springs and seepage.

Custodio (2000), however, argues that though undesirable consequences appear when abstraction exceeds recharge, often there is no clear proof of the same being the cause of these undesirable consequences. This is true in case of Gujarat and West Bengal. In case of Gujarat, increasing incidence of fluoride in groundwater is a major problem whose causes are not clearly known. Fluoride content in groundwater can increase due to leaching of fluoride containing minerals present in geological formations with groundwater - a phenomenon not directly linked to over extraction of groundwater. Similarly, in West Bengal, there were widespread incidences of high levels of arsenic in groundwater threatening drinking water supplies and public health (Mc Arthur *et al.*, 2001). Though there are many competing theories[3], it is seldom attributed to over exploitation.

Thus, the concept of groundwater over development or aquifer over exploitation does not appear to be simple, merely linked to recharge and extraction balance, but is rather complex linked to various undesirable consequences. Therefore, an assessment of groundwater over development involves complex considerations such as fundamental rights, basic survival needs, health, and economic, ecological and ethical issues and hence it is not possible to capture its essence with simple definitions.

It is nevertheless important to mention here that there are fundamental differences in the way these undesirable consequences are perceived by various scholars. For instance, according to Custodio (2000), it is predominantly the point of view of over concerned conservationists, and people suffering from real or assumed damage, and not always of well-informed people. Collin and Margat (1992) have argued that this is an unconscious or incited over reaction to a given situation, while Custodio and Llamas (1997) and Llamas (1992a) assert that this is the result of deeply entrenched "*hydromyths*". Custodio (2000) further opines that the groundwater developers take the opposite position, which focus on beneficial use and use the concepts of safe yield, or rational exploitation and the economics side of sustainable development to present their viewpoints.

Such a logical framework for analyzing the various viewpoints does not hold in several situations, including ours. First of all, the framework assumes that there are conservationists and those who are suffering from the damage, which is real or assumed, are different from the developers. This is not true. In many situations including the one under consideration both are the same. It is the rural communities especially the farmers who are mostly engaged in groundwater development for irrigation, and the consequences or the damage are also primarily borne by them in terms of increased extraction costs, reduced well yields, and quality deterioration. Therefore, the argument that the concerns about over exploitation are an unconscious over reaction to a given situation or are the result of deeply entrenched hydromyths itself is questionable.

On the contrary, more systematic debates about groundwater over development mainly initiated by the researchers and scholars, including those from official agencies and NGOs, were driven by concerns of maintaining sustainable water use in drinking water sector and agriculture. Official agencies mainly looked at farmers as the main culprits behind uncontrolled exploitation of groundwater while researchers and scholars from development circles blamed the government policies and institutional framework. Several researchers from India have pointed to the need to integrate the concerns of intra-generational equity (Saleth, 1994), social development, fundamental rights and economic efficiency (Moench, 1995) and economics of well irrigation (Kumar *et al.*, 2001) in assessing over development of groundwater.

In India, the official versions of over development were primarily based on estimates of recharge and extraction. Therefore, they continued to treat areas with recharge exceeding the extraction as areas suitable for further exploitation without worrying much about the consequent effects. Those areas, where the average annual extraction figures exceeded the annual recharge figures, were treated as over exploited areas without

[3] Three mechanisms were used to explain the release of arsenic to groundwater and are as follows: 1] reductive dissolution of FeOOH and release of sorbed arsenic; 2] oxidation of arsenic pyrite; and, 3] anion exchange of sorbed arsenic with phosphate from fertilizer. However, Mc Arthur and others (2001) postulated another hypothesis, which challenged the oxidation and anion exchange theories, that distribution of arsenic pollution is controlled by microbial degradation of buried peat deposits, rather than distribution of arsenic in aquifer formations, and the former drives reduction of FeOOH.

giving due considerations to factors such as absence or presence of static groundwater storage. Nevertheless, there have been some recent changes in the official perceptions about groundwater over development, as a result of the recognition of the need to integrate economic and social considerations in assessing degree of exploitation. This has come out of observation of field realities. For instance, in certain cases, regions which are declared as safe are facing acute drinking water scarcity. Similarly, in certain other cases, such regions are facing long term decline in water levels (GoI, 2006). This new recognition is also reflected in the methodology proposed by Ground Water Estimation Committee of 1997. But, how far such concerns are integrated in actual assessment is not clear. We would take up this issue for further discussions in the subsequent section.

Though groundwater scientists had emphasised the need for maintaining safe yields and sustainable levels of extraction to promote development with minimum negative ecological, economic and social consequences, the manifestations of over development appear much earlier in certain areas. Thus, such concepts have really not found any place in practical and policy debates. Part of the reason is the realization that ownership rights in groundwater are not well-defined and well development is highly decentralized under private initiatives and government does not have any control over the amount of groundwater that farmers pump. In sum, both the estimates based on field manifestations and official data (of recharge and extraction) are static and short-term interpretations of the situation. They do not capture the complex physical characteristics and behaviour of aquifer systems, including large static groundwater storage, long-term effects, salinity and water quality issues, leakage from aquitards, the system recharge and discharge changes and the uncertainty.

3.2 Definition and Assessment of Groundwater Over-exploitation

Several researchers have tried to define groundwater over exploitation and evolve criteria for assessing degrees of over development, which integrate some of the concerns or considerations discussed early. The 1986 Regulations of the Public Water Domain of the Spanish Water Act (1985), define overexploitation by its effects: an aquifer is considered over exploited or in the risk of exploitation, when the sustainability of existing uses is threatened as a consequence of abstraction being greater than one, or close to, the annual mean volume of renewable resources, or when they may produce a serious water quality deterioration problem (Custodio 2000). Young (1992) defined over exploitation from an economic point of view, de-linking pumping rates from mean recharge values, as the non-optimal exploitation.

Llamas (1992b) introduced the notion of strict over exploitation – leaving room for definitions with broader scope as groundwater abstraction producing effects whose final balance is negative for present and future generations, taking into account physical, chemical, economic, ecological and social aspects.

The concept of sustainability used in the context of natural resource development by the Bruntland commission (Bruntland *et al*., 1987) based on the principle of inter-generational equity is also used to define groundwater over exploitation[4] (Custodio 2000). However, Georgescu-Reogen (1971) and Custodio (2000) have argued that the concept is too broad and cannot be applied to local specific situations, as it does not take into account the impossibility of complete recycling of matter. Another point of contention of Custodio (2000) is that if one strictly follows the principle of sustainable development, as proposed by the Commission, the non-renewable resources like the large and deep confined aquifers of arid regions yield no benefit to anyone. Thus, there is need for improving or extending the definition of sustainable development, for it to be applicable to aquifers.

Finally, the way over exploitation is perceived depends on points of views of different stake-holders involved such as farmers, water development administrators, ecologists, conservationists, mass media, naturists, and citizens and professionals such as engineers, scientists, economists, management specialists, environmentalists, lawyers, sociologists and politicians (Custodio 2000).

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[4]The two major principles of sustainable development are: [a] the rate at which renewable natural resources are exploited should be less than the rate of regeneration; and [b] the waste flow into the natural environment should be kept less than its assimilative capacity.

For instance, one of the dominant perceptions of the farmers about the consequences of over development - falling water levels, drying up of wells etc. - is that it happens due to frequent failure of monsoons and the long term sharp declines in annual rainfalls, sharply affecting natural recharge rates. In fact, declining rainfalls is a hydromyth existing among millions of farmers in the region[5] . Nevertheless, the farmers seem not to see well proliferation and increased groundwater draft as major factors leading to over development. On the contrary, they see droughts as a major cause of depletion. Farmers fail to recognize that droughts are not a recent phenomenon, but a cyclic phenomenon.

On the other hand, the official agencies claim with the support of their data of recharge and extraction that there are no reductions in the quantum of recharge over time[6] . However, here we do not rule out the chances of bias in the estimates as they are often influenced by strong political interests. The direction of such a bias could change depending on the kind of vested interest. If the vested interests are for drilling more wells, the attempt will be to show lower rates of groundwater level drops and over estimate the recharge figures. If the vested interest is in large surface irrigation project in an area, which has considerable well irrigation, the attempt made would be to overplay the signs of over development and unsustainable nature of present use of groundwater. Custodio (2000) has also mentioned about this bias and manipulation as an important factor influencing the perception of over exploitation

The official perceptions of over development are driven by aggregate views. They tend to compare figures of recharge and extraction rates for administrative boundaries or natural boundaries of aquifers. In the process, they miss out several hidden phenomena such as excessive draw-downs in water levels due to large well-fields, groundwater pollution, and excessive rise in water levels causing water logging, which are often localized. Economists' perception of over exploitation is often based on consideration of the cost of abstraction of groundwater, including investment for hitting groundwater and the number of attempts farmers have to make to hit water table. Whereas, the politicians perceive scarcity of groundwater for meeting basic water needs of the communities as signs of over exploitation, and this does not have much to do with the level of groundwater draft against recharge.

In sum, defining and assessing groundwater over development are both difficult and complex and not amenable to simple formulations (Custodio, 2000). According to Custodio, the reasons for this are as follows:

- Varying perceptions of people concerned-for instance, in Gujarat, often, ordinary people and the media refer to problems related to physical availability of groundwater, availability of economically accessible groundwater resources, groundwater quality problems, and seasonal
- The arguments about long term declining trends in rainfall are also contested in the case of Gujarat (Bhatia 1992). However, the detailed analysis of the time series data on magnitude and pattern of rainfalls–including the number of rainy days, duration and intensity-are absent making it difficult to evaluate the impact of rainfall on groundwater recharge
- In fact, the official data for Sabarmati Basin shows that the recharge had gone up during 1992-97 as compared to the period 1987-91 (GoG 1992 and 1999)
- Drops in water levels as a groundwater over development problem. It is only in hydrology and geo-hydrology circles that such distinctions are ever made
- The terms used to define over exploitation vary with space and time
- Persistent draw down trend is not a clear indicator-groundwater behaviour being very complex in multi-aquifer systems-with several variables contributing to inflows and outflows - groundwater level trends are not always clear indications of over development and under-development
- Difficulty in calculating aquifer recharge and integrating water quality with quantity
- Difficulty in assessing long term trends in recharge rate that are very important
- Importance of localized effects in the overall picture
- Changing social perceptions and priorities

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- Improvements in water use technology
- The need to consider the net socio-economic benefits
- Complex nature of cost-benefit calculations and
- Use of scarce, poor, and inappropriate data to define over development

Therefore, in this paper, we take some illustrative cases to demonstrate that the magnitude of groundwater resource problems in India is much different than what the official figures project if we try to integrate some of the complex considerations that determine the degree of over exploitation, in our assessment. They include long-term water level trends, detailed groundwater balance, seasonal water level trends, and negative social, economic, ecological and ethical consequences.

4. EXISTING METHODOLOGIES FOR GROUNDWATER RESOURCE ASSESSMENT: STRENGTHS AND WEAKNESSES

During the past nearly three decades, 4 committees were constituted to propose scientific methodologies for assessment of groundwater development by the Central Ground Water Board of the Ministry of Water Resources. The first committee was in 1979, named Groundwater Over-exploitation Committee (1979). The second committee was constituted in 1984 named the Ground Water Estimation Committee (GEC-84), and the third one was in 1997 named Ground Water Resource Estimation Committee 1997. For our discussions, we would consider the last 2 methodologies only.

4.1 GEC-1984 Criteria and Methodology for Assessing Groundwater Development

GEC 1984 proposed a simple criterion for assessing groundwater development, which is based on net groundwater draft against the gross groundwater recharge. It proposed 2 methodologies for assessing groundwater resources, for administrative units such as blocks and districts. The first is water level fluctuation approach. This is suggested when sufficient numbers of observation wells for monitoring water levels are available within a given administrative unit in question. In this approach, the average annual recharge (R_e)from precipitation is calculated by the following equation.

$$R_e = (A_s * W_f * S_y) + D_w \quad \text{.......................(1)}$$

Here " S_y" is the specific yield of the aquifer, W_f the average water level fluctuation during monsoon, A_s the area of the aquifer, and D_w the pumping during monsoon.

The 5 year average of the annual fluctuations in groundwater levels between pre- and post-monsoon time, multiplied by the specific yield values and the geographical area of the aquifer gives the total recharge.

A major limitation of the GEC-1984 is in the criterion used for assessing groundwater development. At best, it works for simple aquifer units, and cannot capture the groundwater dynamics in complex aquifer systems. Water level fluctuation is the net result of recharge, discharge, return-flows, leakage from across the system, lateral inflows and outflows. But, the water level fluctuation approach to estimating recharge - which often uses values of fluctuations in water levels within one or two layers of the aquifer system - does not allow any discounting for the contribution from the existing storage from other layers of the aquifer, which could be very significant in the cases of deep alluvial aquifer systems with several layers.

Also, in many basins, groundwater contribution to stream-flows in the form of base flow is significant, and constitutes the lean season flows of the rivers (Sohiquilo and Llamas, 1984). For instance, Kumar et al. (2006) found in the case of Narmada river basin that in spite of increase in groundwater draft, the annual rate of decline in groundwater levels had decreased over time. This could be explained by significant reduction in groundwater outflows into surface streams, resulting from lowering of water levels. Outflows are losses from the aquifer, and reduce the effective annual replenishable groundwater. But, GEC-1984 neither included base flow as a determining factor, nor suggested procedure for estimating it. These omissions can lead to an over estimation of the utilizable groundwater, implying negative consequences for stream flows.

Further, the criterion used in GEC-84 for assessing groundwater development use aggregate figures of recharge and extraction. But, recharge is often confined to certain layers within the aquifer system – most commonly the upper shallow aquifer. So far as abstraction is concerned, there could be layers of the aquifer system, which are tapped but do not get natural replenishment either from rainfall or from leakage. As a result, different layers of the aquifer can undergo different degrees of exploitation. It would be different from what the aggregate figures of recharge and abstraction show, and would be actually reflected in the water level fluctuations in the respective aquifer layer. Since the existing methodology treats the entire aquifer system as a single aquifer, it fails to assess the degree of exploitation in different aquifers under consideration.

Further, a simplified criterion can lead to large errors in estimation of groundwater recharge. For instance, the approach of estimating recharge also considers the abstraction during the monsoon period (see Equation 1). Though the abstraction could come from more than one layer, the entire amount is attributed to a single recharged aquifer whose water level fluctuation data are available. The error in the estimation of recharge will be inversely proportional to the contribution of the recharged aquifer in the total abstraction during the monsoon period.

One of the outcomes of using such simplistic criterion is that recharge-abstraction balance of the aquifer does not often correlate with water level trends, a variable which groundwater managers and users are equally concerned with. Maintaining abstraction levels far below annual recharge does not mean that draft is within safe limits. There could be continuous outflow of water into natural drainage systems due to which water levels can decline. On the other hand, a steady recharge-abstraction imbalance does not mean decline in water levels in the aquifer. The aquifer under study might receive the entire recharge from lateral inflows, as well as from top, while several overlying aquifers might be contributing to the abstraction from the system. But, the criteria used in GEC-1984 are too simplistic to capture the complex hydrological considerations, and therefore is not realistic.

In the second approach of GEC-1984, use of ad hoc norms is suggested for the following: a] recharge from rainfall; b] recharge due to seepage from unlined canals; c] return flow from irrigated fields; d] seepage from tanks; and, e] influent seepage from rivers and streams. Separate norms are used for estimating rainfall recharge for different types of geological formations, such as alluvium, semi-consolidated rocks, and hard rocks (see Table 1).

Table 1: GEC-84 Norms for Estimating Recharge from Annual Rainfall

Sl. No	Nature of Geological Formation	Recharge Rate as a percentage of Rainfall
1.	Alluvial formations I] Alluvial sandy areas II] Alluvium with clay content	 20-25 10-20
2.	Semi consolidated rocks	10-15
3.	Hard rocks	4-10
4.	Limestone and sandstone	3-10

Source: NABARD, 2006

Return flow from irrigated fields are estimated using the norm of 35% of the irrigation dosage for surface water, 40% for paddy fields irrigated by surface water; 30% of the water delivered at the outlet for well irrigation, except for paddy; and 35% for paddy fields irrigated by well water (NABARD, 2006). Use of such ad hoc norms can invite many sources of errors. For example recharge from rainfall is a function of not only the formation geology, but also rainfall pattern, soil type, vegetation cover, geo-hydrological environment and the hydraulic conductivity of the soil in the root zone and below. Again, many regions in India face extreme variability in rainfall and rainy days, and recharge from rainfall is not a linear function of rainfall magnitude. As a result, using normal values of rainfall for recharge estimation can lead to significant errors. Further, for a given crop, return flow from irrigations is a complex function of total quantum of irrigation water dosage; the irrigation schedule; and agro-hydrological variables that actually determine the return flows from irrigated fields, which are determined by soil hydraulic properties; drainage conditions; agro-meteorology; and crop characteristics (Jos van Dam, 2006).

4.2 GEC-1997 Criteria and Methodology for Assessing Groundwater Development

The GEC-1997's criterion for assessing groundwater development is far more realistic, and has a better scientific basis than that of GEC 1984. First of all, it proposes assessment of recharge for monsoon and non-monsoon periods separately. Also, the methodology proposes analytical approach for estimating specific yield using groundwater balance for non-monsoon period. It also proposes detailed analytical approach for estimating recharge during monsoon using water level fluctuation approach involving various components of groundwater balance such as storage change, the return flows from irrigation to groundwater, base flows from groundwater into streams and recharge from streams into groundwater, net lateral groundwater inflow into the area and groundwater draft.

The methodology for estimating base flow and lateral flows for administrative units, proposed by GEC-1997, however, is not robust. As one would expect, arriving at reasonably accurate figures of these two variables is essential to deduce figures of monsoon recharge. The reason is pre-post monsoon water level fluctuation, which the methodology banks on for estimating monsoon recharge, is a result of the storage change occurring in the groundwater system due to many inflows and outflows. They include rainfall recharge, net lateral inflows, contribution of stream-flows into groundwater system, return flows from irrigation, groundwater draft, and base flow into streams.

If the assessment unit is a watershed, a stream gauge station can provide data for calculation of base flows, and hence the challenges are less. But, only a few states are taking watershed as the unit for groundwater assessment, and even in these cases, reliable data on stream-flows are not available, as many lower order streams are not gauged.

While base flow during lean season for administrative units is estimated on the basis of groundwater draft during the season, and the water level fluctuation and the specific yield values, its reliability would depend heavily on the accuracy of estimation of groundwater draft figures. But, these figures are normally estimated using certain ad hoc norms. We would deal with the issues associated with groundwater draft in section 4.3. If data on specific yield are not readily available, it can be estimated using groundwater balance by taking watershed as the unit which would again involve the use of groundwater draft estimates for the watershed. In nutshell, estimation of base flow would involve a lot of errors. This is evident from the groundwater resource assessment for Madhya Pradesh provided by Central Ground Water Board (GoI, 2005) for the year 2005. It shows that the total groundwater outflow during lean season is only 1860 MCM. This is a sheer underestimation, when we look at the total amount of lean season flow (from December to May) in just one of the many river basins of Madhya Pradesh, i.e., Narmada alone is 1653.22 MCM (GoI, 2005), and that many perennial rivers are originating from the region.

Again, the figures of recharge so obtained include recharge from irrigation, water harvesting structures, and return flows as well. Here again, no scientific methodology is employed for estimating recharge from irrigation return flows. Instead some modified versions of the earlier norms of 1984 are used. The norm of return flow as a percentage of irrigation dosage, changes according to the depth to groundwater table. For areas with water table higher than 25 m, the norm is 5% of irrigation dosage; for water table depth between 10-25 m, the norm is 10% of irrigation dosage, and for depth to water table less than 5m, is taken as the recharge from irrigation return flows, against 40% and 35% considered in the earlier methodology (NABARD, 2006). In intensively canal irrigated areas of Punjab, Haryana, UP, Andhra Pradesh and Maharashtra, use of such methodologies can lead to highly erroneous estimates of not only return flows but also net natural recharge.

For estimating recharge from water harvesting structures, a uniform rate of 1.4 mm/day is assumed for tanks and ponds based on the average area of the pond (NABARD, 2006). But, in hard rock areas of Peninsular India with large number of tanks and ponds, such assumptions can be unrealistic, and can lead to over estimation of recharge from recharge structures. The reason is sustainability of recharge from tanks and ponds depends on the hydraulic diffusivity of the aquifers, which is very poor in hard rock areas. The creation of recharge mount in the aquifer underlying the recharge structure can prevent further percolation of water (Muralidharan and Athawale, 1998).

The criterion suggested by GEC-1997 for assessing the stage of groundwater development involves gross groundwater draft against net recharge. The net groundwater recharge takes into account the losses from groundwater system, and net gains from lateral flows. This is a major departure from the earlier methodology as that considered net draft against the gross recharge. As Kumar and Singh (2001) note, such an approach had led to over estimation of recharge and under-estimation of draft, as recharge from irrigation return flows is double counted. Hence, the new methodology had reduced the anomalies due to this. But, when it comes to estimating the net groundwater recharge, neither the state groundwater departments nor the Central Ground Water Board consider the groundwater losses while estimating the net recharge in lieu of the fact that these hydrological variables are difficult to quantify. This is well acknowledged in a recent review of the existing methodologies for groundwater assessment carried out by NABARD (NABARD, 2006). Nevertheless, it is not complex enough to realistically assess groundwater development in multi-aquifer systems, where aquifers which get replenished and aquifers which are subject to hydrological stresses could be different.

GEC-1997, however, recommended that hydrological data of recharge and abstraction estimated for the administrative units should be integrated with data on mid-term and long-term trends in water levels to make the final assessment about the stage of groundwater development in areas, which are showing continuous decline in groundwater levels. But, this is hardly done in actual practice by central and state agencies.

4.3 COMMON INADEQUACIES IN GEC-84 AND GEC-97

The biggest challenge posed by the methodologies proposed under both GEC-84 and GEC-97 is in estimating the specific yield values of aquifers to which the recharge estimates are highly sensitive. The issue is very crucial for hard rock areas, as specific yield values could vary widely within small geographical areas (NABARD, 2006). While groundwater balance during non-monsoon period can be used to estimate specific yield, this would require realistic estimates of groundwater draft during the season. Lack of reliable data on groundwater draft is a major factor affecting the reliability of the entire exercise of assessing the stage of groundwater development, as the inaccuracy in estimation of this parameter increases the inaccuracy in estimation of both denominator and numerator.

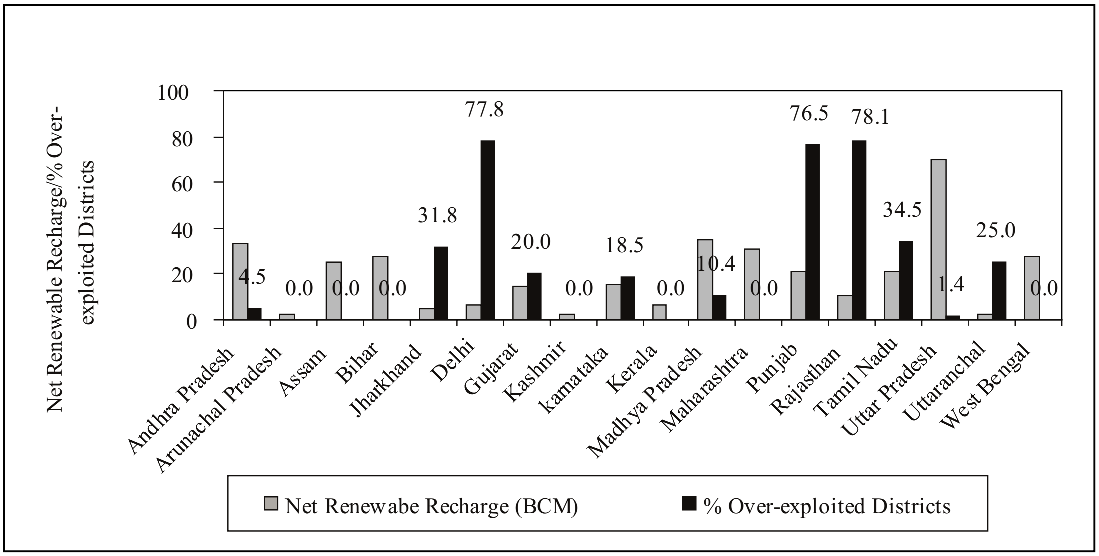
Both the committees proposed estimation of groundwater draft by three different methods: 1] using the well census and the norm of annual draft for different types of wells; 2] using electric power consumption, and the estimate of quantity of water pumped per unit power consumed; and, 3] using groundwater – irrigated area under different crops and the water requirement for each one. All these three approaches suffer from inadequacies. As regards the first one, it is hard to get the exact number of operational wells in a region at a given point of time, especially in hard rock regions, due to increasing incidence of well failures and farmers owning many wells at a time. Further, when it comes to quantifying the amount of water abstracted, wide variations in well outputs are seen within regions, and over the seasons. In case of the second method, it does not take into account the water abstraction by diesel wells that are in operation in many shallow groundwater areas in Orissa, Uttar Pradesh, Bihar, Assam, West Bengal, Madhyra Pradesh and some parts of Gujarat, Kerala and Andhra Pradesh. As regards the third one, the challenge is in getting reliable data on the groundwater-irrigated area under different crops, as data on source wise gross irrigated area are not compiled by most state governments.

In nutshell, both GEC-84 and GEC-97 suffer from problems in the criteria used for assessing the stage of groundwater development. The criteria used in GEC-1984 are only physical, involving only simple hydrological variables such as groundwater recharge and abstraction. Whereas in GEC-1997, the criteria used are a little more complex with the inclusion of base flows and lateral flows, and replacement of gross recharge by net recharge and net draft by gross draft. However, none of them involve complex hydro-dynamic, economic, social and ecological variables that help determine the negative consequences of groundwater over exploitation. Some of them are long-term trends in water levels, depth to water table, cost of abstraction of groundwater, and availability of water in wells during lean season. This apart there are issues of reliability in estimation of groundwater recharge and draft.

5. HOW SERIOUS ARE GROUNDWATER OVER-EXPLOITATION PROBLEMS IN INDIA?

The first set of alarms about groundwater over exploitation were raised almost three decades ago based on observations for a selected locations in India, including Mehsana in north Gujarat, coastal Saurashtra and Kachchh, Coimbatore in Tamil Nadu, Kolar in Karnataka, and Jaipur in Rajasthan. Several scholars had looked at the problem of groundwater depletion from many disciplinary angles (see Dhawan, 1997; Janakarajan, 1994; Moench, 1995; Phadtare, 1988).

Figure 1: Net Renewable Recharge Vs Stage of Groundwater Development



Dewas district located in Narmada valley in Madhya Pradesh was another region, about which a lot had been written (see for instance, Shah et al., 1998). Over the years, several new regions have been classified as falling under over exploited category. Punjab is one such region where many blocks were shown as experiencing falling water table conditions. There has been a lot of whistle blowing about the impending groundwater crisis in many arid and semi-arid regions based on anecdotal evidences from some of these regions on groundwater level trends.

But, if one goes by the official estimates of groundwater development in 2005 from CGWB, only 23.1 Million hecter meter out of the 43.2 Million hecter meter of renewable groundwater in the country is currently utilized (GoI, 2005). Again, if one goes by the most recent disaggregated data, only 15% of the groundwater basins in the country are over exploited; 7% critically exploited. Nearly 62% of the groundwater basins are still "safe" for further exploitation (GoI, 2005). Interestingly, as per the official statistics, it is Punjab is one of the states where over exploitation is most serious, next only to Rajasthan and is followed by Delhi and Gujarat. The number of over exploited districts in the hard rock areas of Andhra Pradesh, Tamil Nadu and Saurashtra in Gujarat, where high incidence of well failures is reported, is very low (see Figure 1).

Therefore, such "doomsday prophecies[7] " have not been based on rational view of the scenario using data on hydrological changes and hydrodynamics. This is not to say that groundwater over exploitation is not a cause for concern in India. In the subsequent section, we would examine how far these doomsday prophecies are correct.

[7]Collin and Margat (1992) have argued that this is an unconscious or incited over reaction to a given situation, while Custodio and Llamas (1997) and Llamas (1992a) assert that this is the result of deeply entrenched hydromyths. Custodio (2000) further opines that groundwater developers take the opposite position, which focus on beneficial use and use the concepts of safe yield, or rational exploitation and the economics side of sustainable development to present their viewpoints.

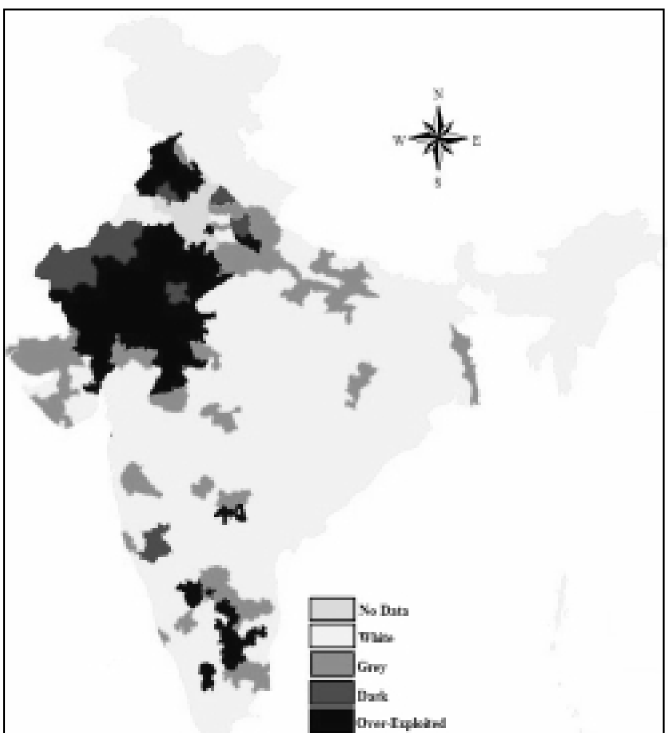
5.1 What Do Water Level Trends Really Mean?

Groundwater level trends are a net effect of several changes taking place in the resource conditions owing to recharge from precipitation, return flows from irrigated fields, seepage from water carriers (canals, channels etc.), abstraction or groundwater draft, lateral flows (either inflow or outflow) or outflows into the natural streams (Todd, 2003). In a region, where long term levels of groundwater pumping are less than the average annual recharge, the groundwater levels can experience short term declining trends as a result of drastic increase in groundwater pumping owing to monsoon failure. But, such a phenomenon does not represent the long term trends. It is important to note here that semi-arid regions in our country also experience significant inter-annual variability in rainfall (source: based on Pisharoty, 1990; Kumar et al., 2006). Further, it is not correct to attribute all changes in groundwater conditions to hydrological stressed induced by human action.

In a region where groundwater outflows into the surface streams are quite large due to the peculiar geo-hydrological environment, even if the net annual groundwater draft is far less than the net recharge, water levels can decline on an annual basis, as illustrated through a study of surface water groundwater interactions in Narmada river basin in India. This is because of the heavy outflows of groundwater into the surface streams. In such situations, increasing draft over time can actually reduce the rate of decline in water levels on a long time horizon (Kumar et al., 2005). In fact, this is the situation prevailing in many river basins of Central India, such as Mahi, Tapi, Krishna, Mahanadi and Godavari. Such situations also prevail in the western Ghats and north eastern hilly regions. This means in such areas, integrating environmental considerations such as maintaining lean season flows in rivers would limit the safe abstraction rates, to levels much lower than what is permissible on the basis of renewable recharge. Hence, in such regions, estimating the base flows would be very crucial in arriving at the net utilizable recharge, and therefore the actual stage of development of groundwater. We have already seen that the groundwater outflows are not properly accounted for in the estimates of the net recharge. Due to this reason, the estimates show a much lower stage of development than what the region is experiencing.

5.2 Can We Look at Groundwater Balance for Assessing Over-draft?

Figure 2: Groundwater over exploited regions in India



Ideally, in a region where lateral flows and outflows from groundwater systems are insignificant, groundwater over draft can take place if the total evapo-transpirative demand for water (ET) per unit area is more than the total effective rainfall, i.e., the portion of the rainfall remaining in situ after runoff losses, and the amount of water imported from outside for unit area. In many semi-arid to arid regions of India, cropping is intensive demanding irrigation water during winter and summer months. The ET demands for crop are much higher in comparison to the effective rainfall. The deficit has to be met either from local or imported surface water or groundwater pumping. Hence, the change in groundwater storage would be the imbalance between the total of recharge from rainfall and return flows from irrigation, and groundwater draft. In semi-arid and arid regions, natural recharge from precipitation is generally very low. In an area with intensive surface irrigation, a negative balance in groundwater indicates high levels of over draft or deficit in effective rainfall in meeting the ET requirements.

Punjab is a classical example. The region is intensively cultivated and irrigated. Most of Punjab is falling in semi-arid to arid climate. Both these factors make ET per unit area very high. Again effective rainfall is low. The water levels are falling throughout Punjab at a rate of 0.3m/annum (Hira and Khera, 2000). Let us examine the groundwater balance in an ideal situation like in Punjab. The change in groundwater storage (Δ_s) could be written as:

$$R_{rech} + RF_1 \; - NGD$$

But, $NGD = ET + \Delta_{Dep} - (S_I + P_e - RF_I)$

$$\Delta_s = R_{rech} + S_I + P_e - ET - \Delta_{Dep}$$

$$\Delta_s = R_{rech} + RF_1 \; - \{ET + \Delta_{Dep} - [S_I + P_e - RF_I]\}$$

Here, R_{rech} is rainfall recharge; RF_I is irrigation return flow; NGD is the net groundwater draft; Δ_{Dep} is the total of water depleted from the soil during the fallow period and the water stored in the soil profile below the root zone; is the surface irrigation water applied; and P_e is effective rainfall.

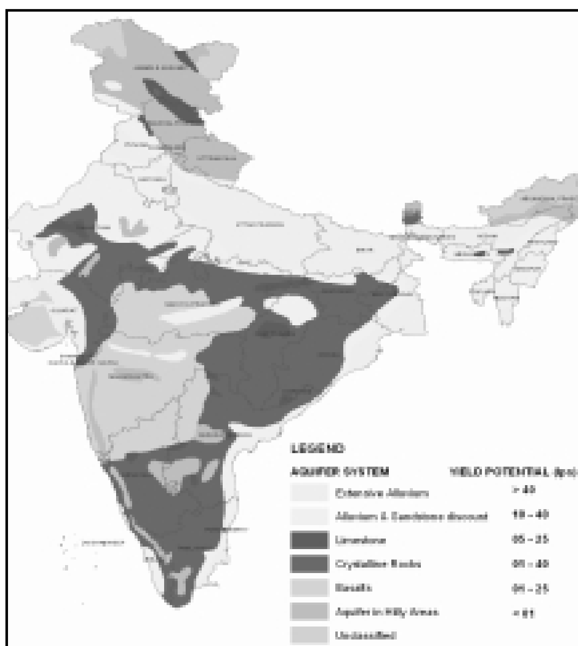
Going by the above groundwater balance equation, if is removed, then the change in groundwater storage would become negative if the entire land is cultivated, which is the condition in almost throughout Punjab. This is because rainfall (P) is less than ET requirement, and as a result, P_e+Recharge also, as P_e+ Recharge would always be less than the total rainfall (P). Hence, surface irrigation's role in maintaining groundwater balance is more than that of the return flows from it, and equals the actual amount of surface water applied. This also means that if water levels are falling even with canal irrigation inputs, then the storage depletion and drop in water levels without exogenous water inputs would be much larger.

S_I

5.3 How Do Geological Conditions Matter?

Under what geological conditions drops in water levels occur is also important in assessing the extent of groundwater over draft conditions. Many semi-arid and arid areas in the country fall under hard rock conditions. Examples are Peninsular India except the western Ghat region, Saurashtra in Gujarat, western parts of Madhya Pradesh, almost the entire Maharashtra and most parts of Orissa (see Figure 3). In these regions, the specific yield of aquifers is very small, 0.01-0.03. Large seasonal drops in water levels are a widespread phenomenon in these areas. During monsoon, sharp rise in water levels is observed and after the monsoon rains, water levels start receding. Many open wells get dried up during summer. Often the drop in water levels between pre and post monsoon is in the range of 5-6 m. So, one should make a clear distinction between seasonal depletion and annual depletion. Further, in hard rock areas, a unit volume of groundwater pumped from the aquifer results in up to 12-13 times the annual drawdown that occurs in alluvial areas for the same amount of over draft. A fall in water level of 1m in alluvial Punjab should be a cause for much greater concern than a 1m fall in water levels in hard rock areas of Tamil Nadu, or Saurashtra or Karnataka given the fact that the specific yield of alluvium in Punjab

Figure 3: Major Aquifer Systems in India



is in the range of 0.13-0.2. This will be evident from the data on recharge-abstraction balance for 2 distinct regions. This is not to say that magnitude of water level drop is not important. In fact, a sharp fall in water level would also have serious implications for the investment required for pumping groundwater, and also efficiency with which groundwater could be abstracted. Hence, what is more important is at what rate water levels fall on a long term basis.

5.4 Integrating Negative Consequences of Over-exploitation in Assessing Groundwater Development

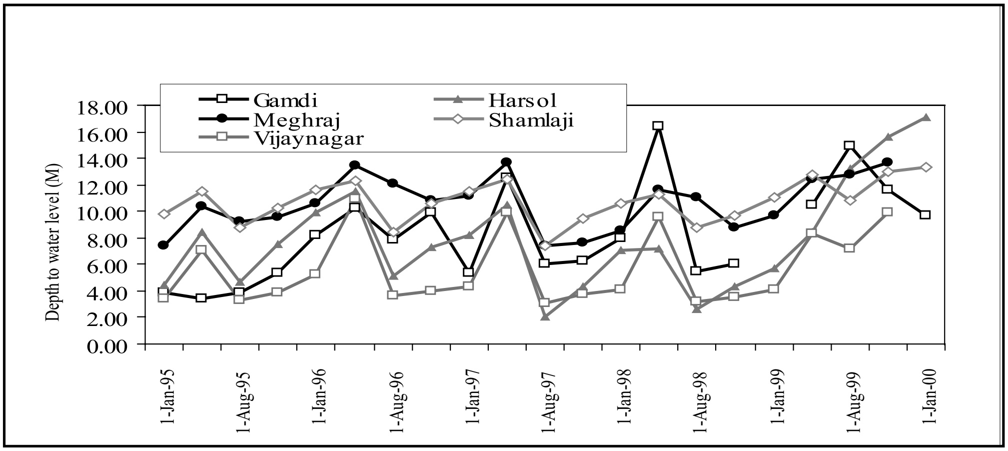
As Custodio (2000) notes, there are many complex considerations involved in assessing groundwater over exploitation in terms of various undesirable consequences. They are hydrological, hydro-dynamic, economic, social and ethical in nature. However, some of the most important ones are: groundwater stock available in a region; water level trends; net groundwater outflows against inflows; the economics of groundwater intensive use, particularly irrigation which takes lion's share of the groundwater in most semi-arid and arid areas; the criticality of groundwater in the regional hydro-ecological regime; ethical aspects and social impacts of groundwater use. Let us examine how the use of these complex considerations in assessing groundwater over draft would change the groundwater scenario in India.

First of all, as regards the groundwater stock, a region with huge amount of static groundwater resources may experience over draft conditions, with resultant steady decline in water levels. The region which can be cited is alluvial plains of the Ganges, whose groundwater stock is many times more than the average annual replenishment (source: based on GoI, 1999). In such regions assessing over draft conditions purely in terms of average annual pumping and recharge may not make sense. In such regions, the long term sustainability goal in groundwater use can be realized even if one decides to deplete certain portion of the static groundwater resources along with the renewable portion, annually (Custodio, 2000). Limiting groundwater use to renewable resources, with the aim of benefiting future generations, can mean foregoing large present benefits.

As regards the influence of water level trends, a region may not experience over draft when pumping is compared against recharge. But, partial well failures could be an area of concern due to the seasonal drops in water levels. Such steep seasonal drops in water levels are characteristic of hard rock areas. For instance, historical data of water levels in 11 watersheds falling in Mulla-Mutha-Pawana shows levels of groundwater development below 20% in 8 watersheds. But fluctuations in water levels between post and pre monsoon were very high in many wells. For instance, in an observation well in watershed no. BM-42 in Dhanori village in Haweli taluka of Pune district shows a decline of 6.4 m during the period from October 1991 to May 1992. Again, during the period from September 1996 to May 1997, a decline in water level of 6.35 m was observed in water levels in the same well. In several years, the drop in water levels during the same period (between October and May) is in the range of 2.75 m - 3.75 m (source: Groundwater Survey and Development Agency, Pune Regional Office, Pune, 2001).

Similar water level trends are found in hard rock area of Sabarkantha district inside the Sabarmati river basin. The water level data of open observation wells obtained from the Central Ground Water Board were also analyzed to understand the dynamics of water level in the shallow aquifers. The analysis of data for the observation wells located within Sabarkantha district available for the 5 year period from 1996 - 00 shows declining trends in water levels from season to season as well as from year to year (Figure 4). For instance, in the case of Vijayanagar well, the water level dropped by 7.71 m from August 1995 to May 1996 owing to pumping; but recovered by 7.27 m during May 1996-August 1996 owning to the recharge from rainfall. More or less a similar trend continued in the next year. The water level dropped by 6.2 m during August 1996-May 1997; then rose by 6.8 m during the monsoon. It is very likely that the shallow wells may have dried up. On the other hand, the water level fluctuation over a 4year period was found to be only 1.27 m an average annual drop of 0.32 m. This is one of the characteristic features of hard rock areas. Large seasonal drops in water levels (upto 25m) can have significant impact on water availability in the wells during dry seasons.

Figure 4: Water Level Trends in Open Wells in Sabarkantha, Gujarat, India



As per official estimates many such regions are still categorized as white and grey, though these areas face severe groundwater scarcity during summer (Kumar et al., 2001). Table 2 shows the data on wells which have failed, and well which are not in use, available from minor irrigation census of 2001 for 12 Indian states. The total number failed wells include both wells which have permanently gone dry and wells which are temporarily not in use. The second category essentially refers to wells which are seasonal, due to seasonal depletion of groundwater. The data shows that the states which are mostly underlain by hard rock formations, both the percentage of wells that have failed and which are not in use are high. For instance, in Orissa, even as per 2005 official data, the stage of groundwater development was only 18% (GoI, 2005). But, a large percentage of dug wells (21.5%), and a much large percentage of deep tube wells (51.8%) have failed. In terms of numbers, a total of more than 79518 dug wells had failed in Orissa by 2001. Likewise, a significant percentage of open wells (17.3%) in Andhra Pradesh have failed by 2000-01, though the level of groundwater development in the state was only 45% even as per 2005 estimates (GoI, 2005). The number of wells, which have failed, is also very large (204761). Similar trend is found in Tamil Nadu and Madhya Pradesh.

Table 2: Well Failures in Different Categories from 8 Major Indian States (2001)

Sr. No	Name of the State	Percentage of Wells which have failed/(Not in Use)		
		Dug wells	Shallow Tube well	Deep Tube well
1.	Andhra Pradesh	17.3/(20.2)	2.4/(2.9)	1.6/(2.2)
2.	Bihar	18/(32.5)	2.7/(4.8)	36.7/(44.9)
3.	Gujarat	19.3/(22)	12/(14.2)	8.5/(12)
4.	Madhya Pradesh	16.2/(18)	14.7/(15.1)	13.9/(16.2)
5.	Maharashtra	9.3/(10.9)	4.3/(7.9)	10.7/(13.6)
6.	Orissa	21.0/(25)	16.5/(19.3)	51.8/(62.8)
7.	Punjab	0/(0)	0/(0)	1.2/(1.6)
8.	Rajasthan	24.9/(27.9)	3.3/(3.5)	7.4/(7.8)
9.	Tamil Nadu	20/(22.1)	7.5/(8.1)	19.7/(20.4)
10.	Uttar Pradesh	4.4/(9.5)	0.80/(1.2)	3.7/(5)
11.	West Bengal	6.3/(10.3)	3.5/(4.4)	9.8/(12.2)

Source: Authors' own analysis based on Minor Irrigation Census data 2001

Note: the figures in brackets show the percentage of wells which are currently not in use due to several reasons.

Similarly, the current district-wise assessment of groundwater development does not take into account the long-term trends, as the latest methodology suggests. A region might have experienced long term decline or rise in water levels; but a few years of abnormal precipitation (either drought years or wet years), may change the trends in the short run. Hence, assessment of over draft conditions should integrate hydro-dynamics, i.e., the way groundwater levels behave.

Another dimension of groundwater over exploitation is economic. The cost of production of water should not exceed the benefits derived from its use, or the cost of provision of water from alternative sources. Drops in water levels beyond certain limit cause negative economic consequences, by raising the cost of abstraction of unit volume of water, not only in irrigation but also in other sectors like municipal uses. Though there could be plenty of water in the aquifers, the fixed cost and variable costs of abstraction of water could be prohibitively high. In alluvial north and central Gujarat and arid Rajasthan, groundwater irrigation is viable due to heavy electricity subsidies. An analysis by Kumar et al. (2001) in Sabarmati river basin of north central Gujarat showed that groundwater irrigation would be economically unviable if the full cost of energy used for pumping groundwater is borne by the farmers.

In many hard rock areas underlain by basalt and granite, the highly weathered zones in the geological formations, which yield water, have small vertical extent-up to 30 m. When the regional groundwater level drops below this zone, farmers would be forced to dig bore wells tapping the zone with poor weathering. The reason is tapping groundwater from strata below this depth using open wells would be not only technically infeasible, but also economically unviable. These bore wells have poor yields, unlike the deep tube wells in alluvial areas such as north Gujarat, alluvial Punjab, Uttar Pradesh and Haryana. For instance, analysis of census data (Table 3) show that as high as 40% of the nearly 85,601 deep bore wells (that are in use) in Andhra Pradesh were not able to utilize their potential due to poor discharge. The figure was nearly 19.1% for Rajasthan, which had sedimentary and hard rock aquifers. The figure was 59.9% for Maharashtra, which has basalt formations. One could see that the percentage of deep tube wells which suffer from poor discharge was very low in alluvial areas of Punjab (0.3%) and West Bengal (0.3%). While the number is very high for alluvial Bihar, the total number (430) is negligible.

Table 3: Percentage of Dug Wells and Deep Tube Wells Suffering from Poor Discharge in Selected Indian States

Sr. No	Name of the State	No. & Percentage of Wells in Use Which Face Discharge Constraints	
		No. of Deep Tube Wells	% of Deep Tube Wells
1	Andhra Pradesh	34216	40.0
2	Bihar	430	12.6
3	Gujarat	20282	24.5
4	Madhya Pradesh	17841	58.5
5	Maharashtra	39958	59.9
6	Orissa	132	7.7
7	Punjab	10	0.10
8	Rajasthan	10010	19.1
9	Tamil Nadu	22838	34.1
10	Uttar Pradesh	3110	9.3
11	West Bengal	15	0.30

Source: Authors' own analysis based on Minor Irrigation Census data 2001

Withdrawal of groundwater from these bore wells creates excessive draw-downs as specific yield and transmissivity values of these hard rock formations are very low. Due to excessive draw-downs and high well interference, well failures become widespread. Therefore, before a farmer hits water in a successful bore well, he/she would have sunk money in many failed bore wells. Due to this reason, the actual cost of abstraction of groundwater becomes very high. The command area of wells is also on the downward trend. For instance, in the case of five districts falling in the basaltic area of Narmada river basin in Madhya Pradesh, the average command area of energized wells were found to be declining almost consistently from 1974 till 2000 (see Table 4). In Betul district, the average area irrigated by a well reduced from 6.97 ha to 2.18 ha during the 26 year period. In Chhindwara, it reduced from 4.56 ha to 2.75 ha. So investment for well construction, compounded by reduction in command area reduces the overall economics of well irrigation. But, this aspect has been captured in the criteria for assessment of over exploitation. As per the official data, these five districts are still in the white category, and safe for further exploitation (GoI, 2005).

Table 4: Reduction in Average Command Area of Wells over Time in Narmada Basin, Madhya Pradesh

Name of District Falling in Narmada Basin	Average Area Irrigated by a Well in ha					
	1974-75	1980-81	1985-86	1991-92	1995-96	2000-01
Balaghat	4.50	2.25	2.35	2.57	1.73	1.96
Chhindwara	4.56	2.58	2.26	1.42	1.50	1.75
Shahdol	2.04	0.18	0.50	0.70	0.99	0.47
Jhabua	2.93	1.87	0.89	1.20	1.26	0.57
Betul	6.97	3.37	3.02	1.98	2.06	2.18

Source: Authors' own estimates based on primary data as provided in Kumar (2007)

Interestingly, the economics of groundwater use is not a function of depth to water table alone, as often perceived. Even in areas with shallow water table conditions the cost of abstraction could be enormously high due to high cost of energy. In Bihar, due to poor rural electrification, farmers are forced to use diesel and kerosene pumps for lifting water from wells. Though the depth to water table is nearly 15-20 feet, it costs them Rs.50 /hour for pumping water with an output of nearly 15 lt/sec. The unit variable cost comes to Rs. 1/m^3 of water. This is higher than the variable cost farmers incur in north Gujarat (Rs.0.50/m^3) for pumping out water from a depth of 400-500 ft.

The economics of groundwater use is not static. Economic viability of groundwater abstraction can change under 2 circumstances: 1] opportunities for using the pumped water for more productive uses emerge with changing times; and 2] the cost of abstraction of groundwater changes due to improvements in pumping technologies, or changing cost of energy for pumping groundwater. With massive rural electrification, cost of groundwater abstraction in Bihar could come down to negligibly low levels. On the other hand, adoption of new high yielding varieties or high valued crops can increase the gross returns from farming.

Social consequences of groundwater use are equally important. One serious issue associated with groundwater intensive use is that it excludes resource poor farmers from directly accessing the resource when water levels start falling. Equity in access to resource (aquifer) should be an important consideration in assessing the degree of over exploitation of aquifers. In many areas, it is only the rich farmers, who are able to pump groundwater, owing to astronomical rise in cost of digging/drilling wells, and they enjoy unlimited access to the resource. While the well owners of Mehsana incur an implicit cost of nearly Rs.0.5/m^3 of water , they charge to the tune of Rs.1.5/m^3 to Rs. 2/m^3 from the buyers. Similar trends were found in Kolar district, in which case the well owners charge up to Rs. 6.5/m^3 of water (source: based on Deepak et al., 2005), against a close to zero

[8] This is based on the capital investment of 10 lac rupees amortized over the life of the tube well (12 years), the annual operation and maintenance costs of Rs. 50,000 and the average volume of 2.5 lac cubic metre of water pumped during a year at a rate of 100m3/hour.

marginal cost of pumping groundwater. In many areas, groundwater intensive use leads to water quality deterioration, causing scarcity of safe water for drinking. In such situations, the draft does not necessarily exceed the recharge. Examples are Saurashtra and Chennai coast, alluvial north and central Gujarat, Gangetic alluvium of West Bengal. While the issue is of salinity in coastal Saurashtra and Chennai, it is arsenic content in deep aquifers in West Bengal (Kumar and Shah, 2004).

Groundwater over use, like the use of other natural resources involves ethical considerations (Custodio, 2000). The ethical considerations concerning water use mainly revolve around the distribution of benefits and costs of water use and risks associated with it (Llamas and Priscoli, 2000). The extent to which wasteful use practices are involved in major sectors of water use and the degree to which water abstraction practices reduce the opportunities of users neighbouring farmer, individual himself, and others are the major issues to be investigated (Kumar, Singh and Singh, 2001). In a water-scarce region, physically and economically inefficient uses should be discouraged. But, in reality, even in regions where acute scarcity of groundwater exists, farmers use traditional irrigation methods that are wasteful; and allocate water to economically inefficient uses (source: based on Kumar, 2005; Deepak et al., 2005). In hard rock areas, competitive drilling by powerful farmers causes reduction in yield of neighbouring wells due to well interference, depriving resource-poor farmers (Janakarajan, 2002; Deepak et al., 2005). In sum, the current assessment of groundwater over exploitation does not give a clear picture of actual intensity of over exploitation in both absolute and relative terms. It tends to underestimate the magnitude of groundwater over exploitation in India, which can be assessed from the negative social, economic and ecological consequences of over development.

6. SUMMARY AND CONCLUSIONS

There are many conceptual issues in defining groundwater over development. First of all, the concept of groundwater over development or aquifer over exploitation is complex linked to various undesirable consequences which are physical, social, economic, ecological, environmental, and ethical in nature. Further, there are varying perceptions of the undesirable consequences. As Custodio (2000) notes, defining and assessing groundwater over development are both difficult and complex and not amenable to simple formulations. The reasons are as follows: varying perceptions of people concerned; the terms used to define over exploitation vary with space and time; difficulty in calculating aquifer recharge and integrating water quality with quantity: difficulty in assessing long term trends in recharge rate that are very important; importance of localized effects in the overall picture; changing social perceptions and priorities; improvements in water use technology; the need to consider the net socio-economic benefits; complex nature of cost-benefit calculations; and use of scarce, poor, and inappropriate data to define over development.

The criteria adopted by official agencies in India for assessment of groundwater over development are inadequate for complex aquifer conditions, and at best give aggregate scenarios of recharge and abstraction for simple aquifer conditions. But, there were some improvements in the criteria and methodologies proposed by various expert committees since 1984. The most significant improvement in the criteria is the inclusion of base flows and lateral flows to determine the net groundwater recharge. The second significant improvement is in the criteria for assessing the stage of groundwater development. GEC-1997 suggests the use of gross groundwater draft against the net recharge, instead of the net draft against the gross recharge. It had recommended the inclusion of all hydrological variables in the estimation.

But, the methodology proposed for estimation of these variables becomes inadequate when the assessment is to be made for administrative units. This is because of the absence of analytical procedure for estimation of base flows during monsoon season, and questionable reliability of the estimates of lean season base flows. Even the CGWB's own assessment of groundwater development takes into account only base flows during lean season (estimated). So, all these can induce major errors in estimation of recharge. But, the challenge becomes mounting when data on specific yield of aquifers are not available. When assessment is to be made for watersheds, the gauge data of stream flows can be used to estimate the base flows during monsoon. Also, the lean season flow can be directly measured.

Leaving aside the issue of doing reliable estimates of recharge and abstraction, the criteria for assessing aquifer over exploitation in India are too simplistic, based on net recharge and gross draft. They not take into account the complex hydrological, geological, hydro-dynamic, economic, social and ecological variables that determine the physical, social, economic, ecological and ethical consequences such as the safe yield of the aquifer, drinking water scarcity during lean season, poor economics of groundwater use, water quality deterioration, equity in access to water, and the efficiency with which water is used.

We have used selected illustrative cases to demonstrate how combining official statistics of groundwater development in the country, with information on detailed water balance, geology, water level fluctuations, and socio-economic, ecological and ethical aspects would cast an altogether different scenario of the degree of over exploitation problems in India. The available assessments of groundwater over exploitation provide a highly misleading picture of groundwater exploitation scenario in India. As per the most recent official estimates, many hard rock regions which are facing problems of reduction in well command, frequent well failures and enormous increase in cost of groundwater abstraction, and seasonal scarcity are shown as safe areas. Many areas in central India, which are facing problems of water level decline, are still categorized as under-developed areas.

To get the assessment of aquifer over exploitation that reflects the concerns of the stakeholders, two steps are important. The first step is improving the reliability of groundwater recharge and draft estimates. The most important challenge is accurate estimation of groundwater draft and natural outflows from and lateral flows in the groundwater system. The accuracy in estimation of groundwater recharge would depend on the availability of reliable data on specific yield values for the aquifer under consideration. The second step is broadening the criteria for assessing aquifer over exploitation to capture the complex hydrologic, hydro-dynamic, economic, social and ecological variables that reflect the negative consequences of over development. For this, a lot of data on socio-economic and ecological aspects of water use need to be generated and combined with the official data.

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